S
625.732
H3n

STATE DOCUMENTS

NOV 11 1974

NUCLEAR MOISTURE DENSITY EVALUATION

MONTANA HIGHWAY RESEARCH PROJECT
IN COOPERATION WITH THE
BUREAU OF PUBLIC ROADS

STATE OF MONTANA
HIGHWAY COMMISSION

MONTANA STATE LIBRARY
930 East Lyndale Avenue
Helena, Montana 59601

550

Montana State Library
3 0864 1006 4667 1

NUCLEAR MOISTURE-DENSITY
RESEARCH PROJECT

by

ROBERT T. RASK

550
Q. 1

State Highway Engineer . . . . Paul M. Johnson

Deputy Highway Engineer . . . . Don B. DeVore

Materials Engineer . . . . Roy H. Gagle

Assistant Materials Engineer . . . . Stephen F. Weber

STATE OF MONTANA

DEPARTMENT OF HIGHWAYS

PLANNING SURVEY

RESEARCH PROJECT

HPR-1 (1)

PROJECT NO. 7906

Nuclear Moisture-Density Research Project

Final Report

1965

TABLE OF CONTENTS

Digitized by the Internet Archive
in 2015

https://archive.org/details/nuclearmoistured1965mont

STATE OF MONTANA
DEPARTMENT OF HIGHWAYS

PLANNING SURVEY
RESEARCH BRANCH

NUCLEAR MOISTURE-DENSITY RESEARCH PROJECT

Final Report

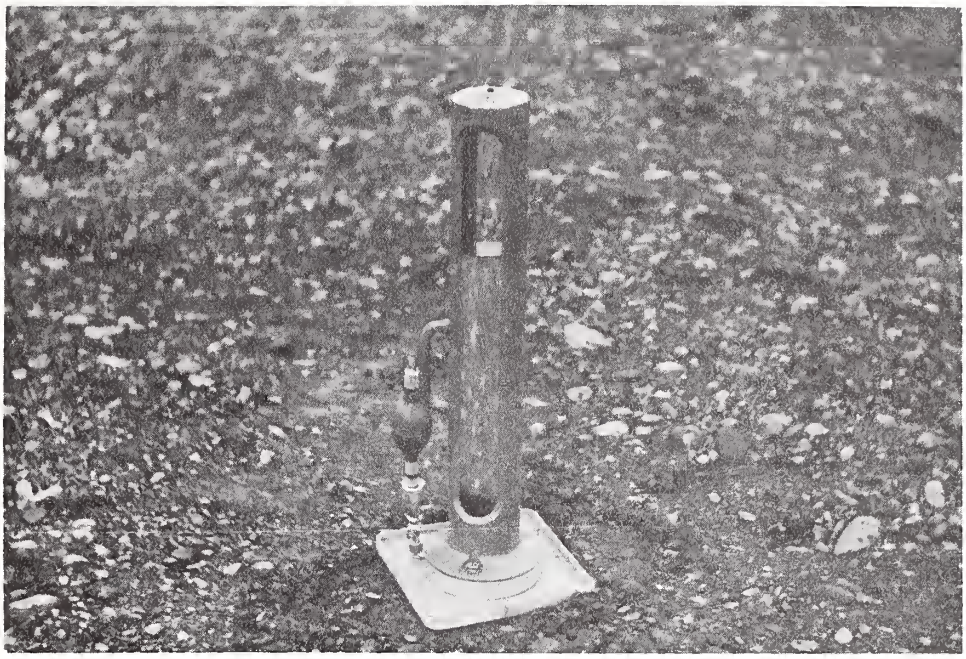
INTRODUCTION

The purpose of this project, as outlined in a proposal submitted to the Bureau of Public Roads on August 28, 1962, is to provide a basis for determining the following:

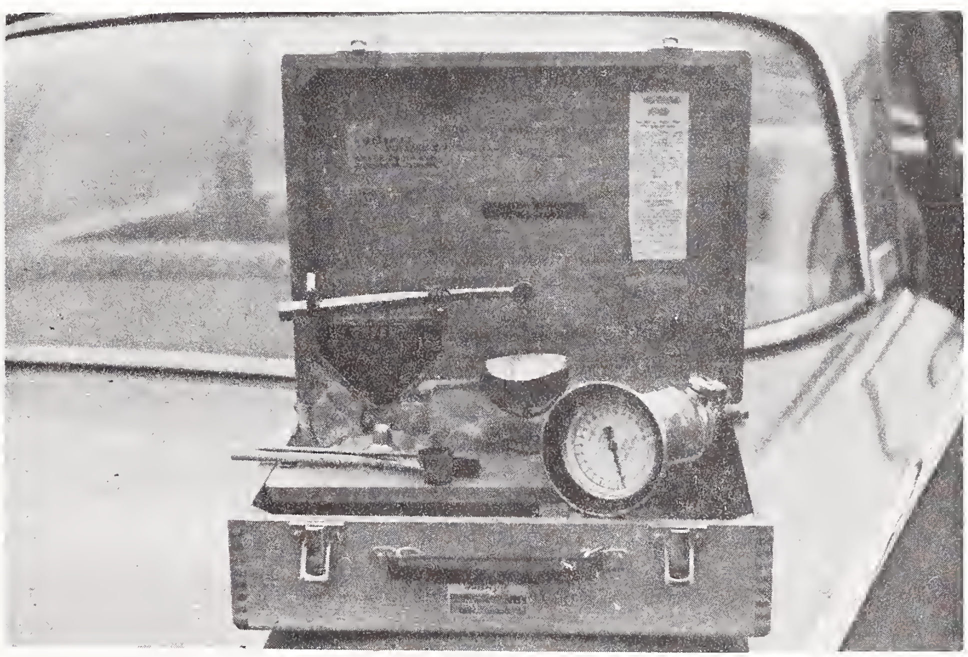
1. Efficiency of the Nuclear Method compared to our present method.
2. Relative costs of Nuclear and present methods.
3. Extent to which the method could profitably be employed.
4. Recommendations as to the manner in which the method is to be employed from the standpoint of supervisory control.
5. The number and distribution of meters required for the entire State Organization.

This research project report constitutes the results of field and laboratory evaluation of the portable nuclear gauge used for measuring in-place soil density and moisture content. Construction projects containing embankment work were tested with the Nuclear device, and comparison testing with the conventional method was made whenever possible. Demonstrations were given in each District to acquaint Highway personnel with the operation of the equipment.

One of the conventional methods used for determining in-place density is the balloon volumeasure. The volume of the test hole is determined by pumping water into a balloon suspended in a graduated cylinder. The volume is obtained when the water level reaches the lowest point in the cylinder.



Rubber Balloon Volumeasure



Speedy Moisture Tester

The soil from the test hole is retained for weight measurements. The density is based on the volume of the test hole and the wet weight of the material removed. At the beginning of this project, the sand displacement method was also used for determining density. The sand is poured into the test hole and leveled with the top. Knowing the weight of sand added, and its density, the volume of the test hole is calculated. The wet weight of soil and the volume of the test hole is used to calculate the density.

Whenever the words "conventional method" are mentioned in this report, they refer to either the balloon volumeasure or the sand displacement method.

The "Speedy Moisture Tester" is used to determine the moisture content. The instrument operates on the principle of a calcium carbide additive reagent being introduced to the free moisture in the sample. This forms a gas, the amount being dependent upon the amount of free moisture in contact with the reagent. The higher the amount of moisture in contact with the reagent, the higher the pressure. A dial gauge on the instrument is calibrated to give percent moisture based on the wet weight of soil. Conversion charts are available for the percent moisture based on the dry weight of the soil.

The information in this report will be listed under the following headings:

(1) Preliminary Study, (2) Field and Laboratory Investigation, (3) Calibration Curves, (4) Radiation Exposure, (5) Cost Comparison, Efficiency, and Distribution, (6) Conclusions, (7) Recommendations, (8) Operating Procedure, and (9) Acknowledgements.

PRELIMINARY STUDY

The instrument purchased for this research project is manufactured in South Africa. The Viatec Hidrodensimeter Model HDM-2 will be referred to in

this report as the Nuclear Device. The instrument was received in late September of 1963. The equipment consists of a portable scaler, surface probe, surface probe calibration unit, graphs for density and moisture determinations, and necessary instructions. A six volt wet battery was used as the external power supply.

Scaler

The instrument is housed in a sheet-metal case measuring $11\frac{1}{2}$" x $11\frac{1}{2}$" x $11\frac{1}{2}$". The main chassis, containing the electronic circuits, is secured to the outlet case. With the exception of the Dekatrons, the triggering circuits, and the high voltage regulators, the Hidrodensimeter Model HDM-2 is completely transistorized. All the counter and direct voltage circuits are constructed on plug-in printed circuit boards. An automatic timer is provided which gives standard one-minute counts. Alternately, by means of a switch, the Scaler can be used for counting over any period of time determined on a stop-watch. The total capacity of 99,999 counts is registered on five Dekatrons.

The main function switch selects the mode of operation. It has three positions -- On, Off, and External Battery -- which are arranged in such a way that in going from external 6-volt battery (On) to an external source, the switching contacts must pass through the (Off) position.

Control of the instrument is provided by three push button switches labeled Start, Stop, and Reset. In the Manual timing position, all of these controls are used. In the Auto position, the Start button operates the automatic timer so that the five Dekatron tubes indicate the number of counts in a fixed, one-minute interval, or CPM. Pressing the Reset button ensures that the counting system is ready for the next measurement. All the connections are made to the top panel by two 9-pin plugs and sockets.

A three-position selector switch controls the type of measurement to be made, as follows:

(a) Moisture - In this position, the counting circuits are connected to the input signals from the neutron tubes of the probe.

(b) Test - In this position, the counting circuits are connected to the output from a test oscillator. This enables the overall operation of the Scaler circuits to be checked.

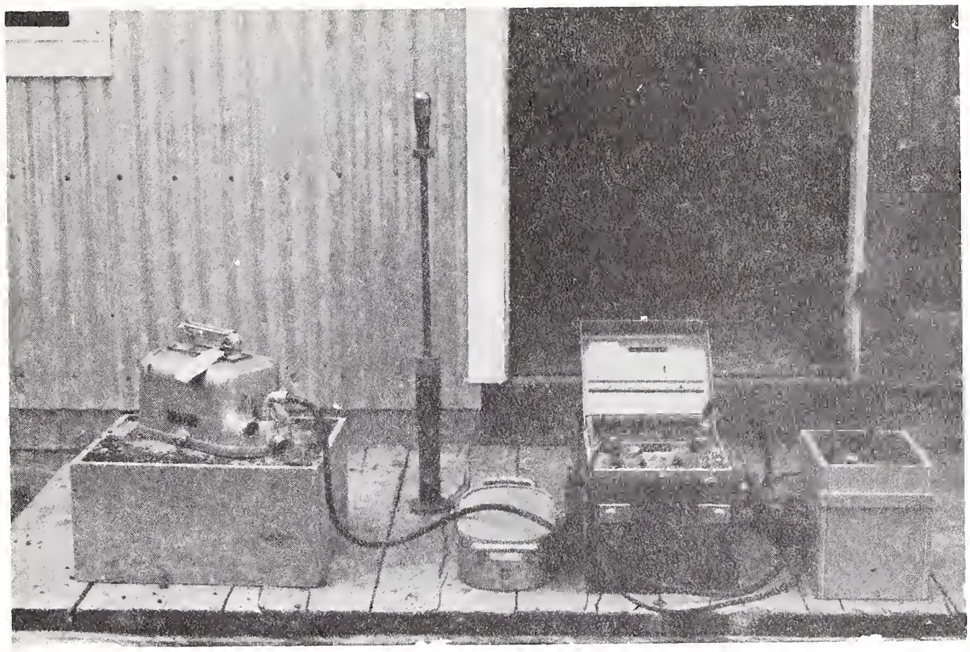
(c) Density - In this position, the counting circuits are connected to the input signals from the Geiger tubes in the probe, and a supply of 950 volts is switched onto the Geiger tubes.

Surface Probe

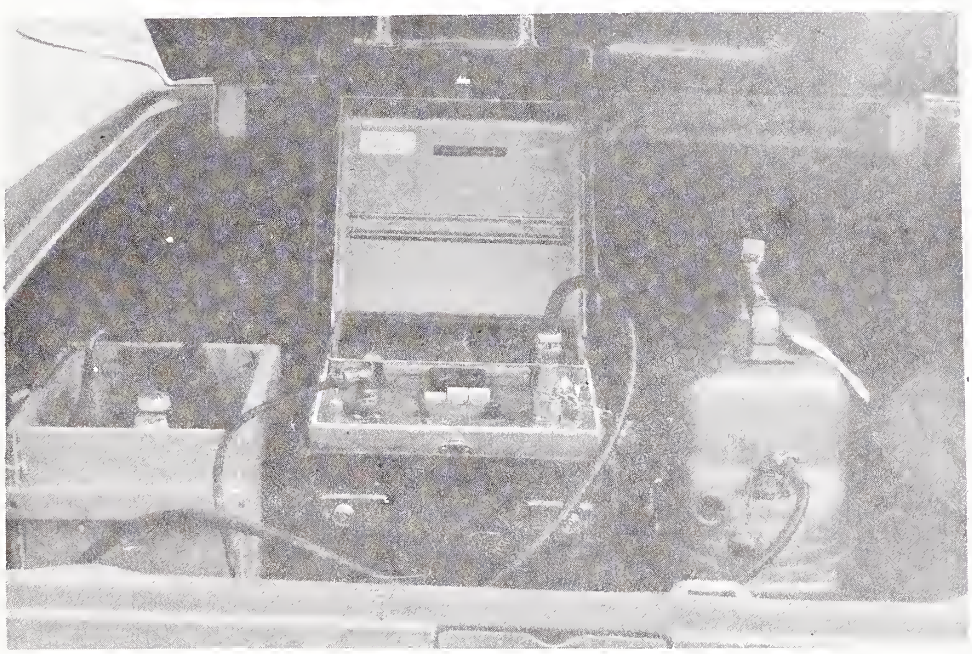
The probe is housed in a cast box measuring 15" x 7" x 9" high. The shape of the top casting is such that the carrying handle is at the center of gravity of the probe. A six-pin socket, into which the connecting cable is plugged, is mounted on the back end of the probe.

The radium-beryllium source is housed in a monel container which is fastened to one end of a stainless-steel shaft. This shaft is free to slide inside a monel cylinder, which contains a quantity of triple-distilled mercury. The top end of the shaft is linked to the pivoted section of the split carrying handle in the following manner: when the handle is raised (in the operating position), the shaft is lowered toward the sole plate of the probe and displaces the mercury which is forced upward in the cylinder; when the handle is lowered (in the carrying position), the shaft is raised and the mercury flows around it, occupying the space underneath the source to a depth of two inches. This provides adequate screening. The source mechanism is encased in a sphere of lead.

The Geiger tubes are mounted on the sole plate, and behind the lead



Nuclear Moisture-Density Equipment



Transporting Nuclear equipment in the trunk of the vehicle

sphere. Two borontrifluoride neutron tubes are also mounted on the sole plate. Preamplifier circuits for amplifying the small pulses from the neutron tubes are assembled on boards which are mounted on the support-column casting.

Surface Calibration Unit

The Surface Calibration Unit provides two calibrated positions to check the overall functioning of the equipment. The unit is designed to take the sole plate of the probe with the minimum of movement, and it consists of an alloy box filled with a material that simulates standard conditions of density and moisture content. Two calibration points make it possible to provide both a low and a high simulated value for both moisture-content and density measurements. Thus, it is possible to check whether the calibration curve has changed. One calibration point is obtained by taking a reading on the Scaler when the probe is in one position on the Calibration Unit; the other point is obtained when the probe is turned through 180°.

Checking the Scaler

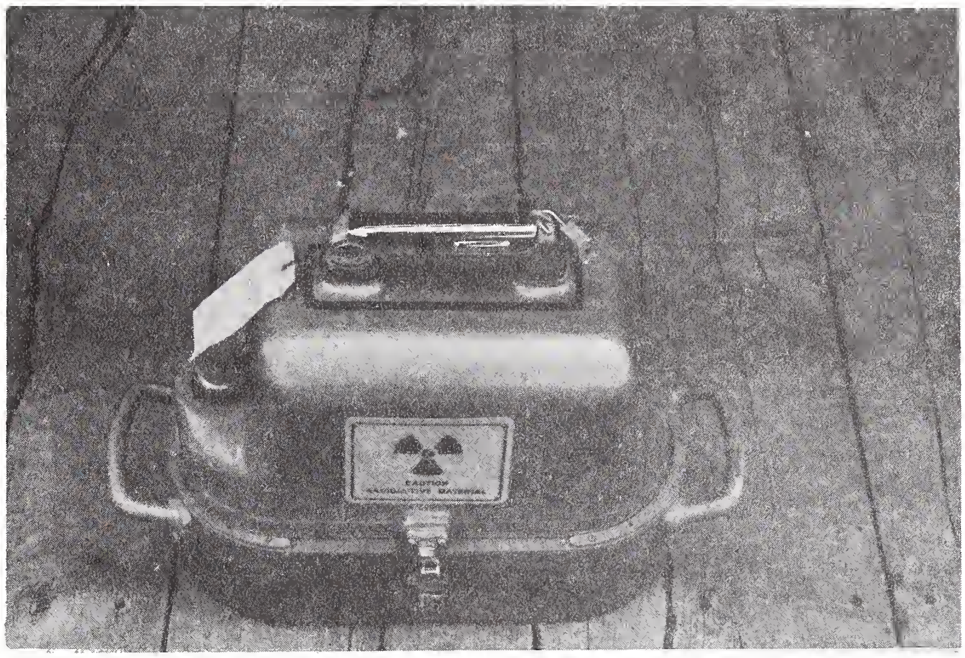
Connect the external six-volt wet battery to the Scaler. The Scaler should be allowed to warm up for a few minutes. Turn the function Selector Switch to the Test position. Press the Start button, and check for counting by all Dekatrons. Switch to Automatic time and determine the repeatability of the instrument over a number of readings.

Checking the Calibration

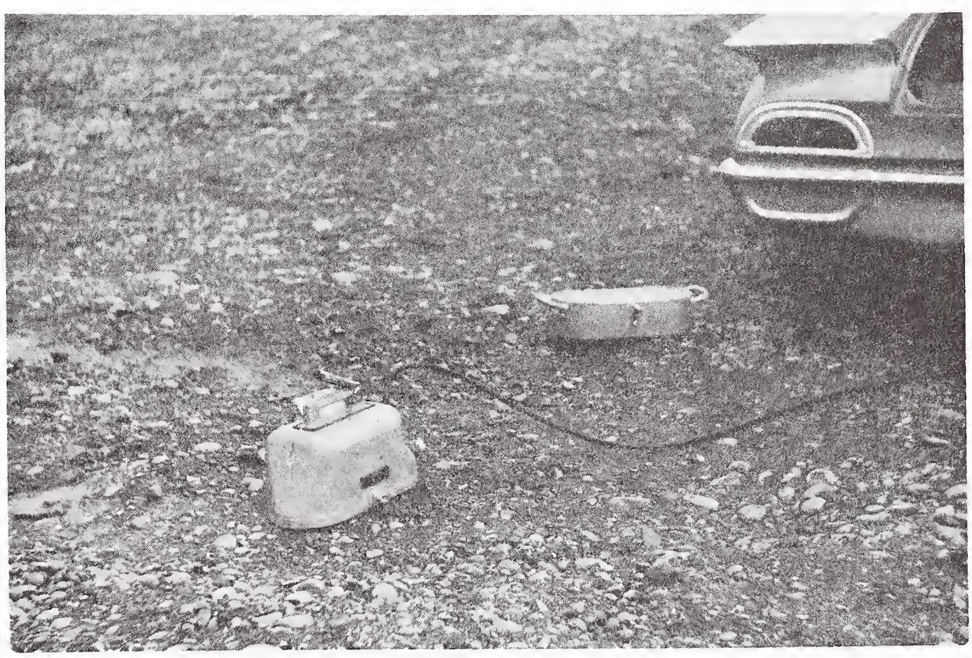
(a) Connect the probe to the Scaler by means of the connecting cable.

(b) Place the Surface Calibration Unit on an open box about 14 inches above the floor.

(c) Place the probe on the Calibration Unit so that the red dot on the cover is over either the letter "A" or "B" on the unit. Make sure the contacting surface of the probe and unit are clean.



Surface Probe on Calibration Unit



Checking compaction near bridge
abutment

(d) Check the counts on both Moisture and Density to see that they are within the specified allowable tolerances for the position used.

FIELD AND LABORATORY INVESTIGATIONS

The Nuclear device was used in District 1 during the last week in September, 1963. Moisture-density tests were run on project I 90-2 (2) 80, Huson - West. The tests were taken in an A-1-a(0) soil.

A smooth area about 18 inches square is prepared with a hand scraper or a shovel. Whenever testing in an area where the contractor was compacting with a sheep's foot roller, the test area was prepared about five inches below the surface. The top few inches seem to give a poor representation of the compaction throughout the fill. Therefore, it was made a common practice to prepare the test area at a depth that the teeth on the sheep's foot would penetrate, this being about five inches below the surface. The above procedure appears to be the best method to follow.

After preparing a smooth area, the surface probe was set on the test site. The probe was slid back and forth until it seemed to lie flat on the soil. Two counts were established for density and two for moisture. The probe was reversed 180°, and two 1-minute counts were taken for density and for moisture. After reversing the probe, the count changed considerably. The area covered by the probe seemed to contain air gaps that had an apparent effect on the back-scattered rays. A thin layer of fine dry sand was spread over the test area. The surface probe was seated on the sand, and a new series of counts was taken. When the probe was reversed, a good check was obtained. Further tests were taken to determine what effect the sand would have on the actual density. These tests were performed on a soil containing clean coarse sand. The probe was seated on the coarse sand, and only a slight variation in count was noticed. The probe was then seated with the

fine dry sand. No appreciable change in count was noticed. Several tests were performed by the above method, and they all seemed to prove satisfactory. At this point in our investigation, the fine sand was used whenever it seemed necessary to insure proper seating.

A calibration curve was established by using both Nuclear and conventional results. The CPM for both density and moisture was established first. The test hole for the conventional method was in the same location as the Nuclear tests. The wet density determined by the conventional tests and the CPM determined by the Nuclear tests were used to establish the calibration curve. The conventional wet densities seemed to be higher than normal. After considerable investigation, an error was found in the weighing of the wet soil. The error was corrected, and better results were obtained. A calibration curve was re-established for the A-1-a(0) soil. Refer to Table No. 1, test numbers 1 through 4.

Comparison testing with the conventional sand method was made whenever possible. Good results were obtained when a reliable conventional test could be made. It appears at this point that this can only be done in a fine soil containing very little coarse aggregate. It becomes apparent in a rocky fill that the Nuclear device measures the density of some of the larger rock not encountered in the conventional tests.

The Nuclear device was used on Project I-IG 90-2 (10) 110 Ul, Bonner - East. The soil is classed as an A-1-a(0). The material contained -3 inch aggregate with clean sand.

The presence of large aggregate makes it difficult to determine densities with the present conventional equipment. Therefore, no comparison measurements were made for this particular project. In checking the time required to complete a series of tests by different stations throughout the

project, twenty moisture-density determinations were completed in about four hours. All of the tests were made using the fine dry sand for seating the probe.

Several demonstrations were given on the projects and in the District 1 Laboratory. Highway personnel were favorably impressed with the speed of the Nuclear device. In one instance, a complete moisture-density was determined behind a pneumatic-tired roller. After the roller passed over the same location again, another test was made. Each time the Nuclear device would show a higher density with slightly less moisture. Refer to Table No. 1, test numbers 17 through 19.

TABLE NO. 1

Location	Test No.	Wet Density ($\frac{lbs}{ft^3}$)		Dry Density ($\frac{lbs}{ft^3}$)		% Moisture	
		Conv.	Nuclear	Conv.	Nuclear	Conv.	Nuclear
Huson - West	1	120.2	110.5	109.4	109.6	9.8	9.7
I 90-2 (21) 80	2	131.3	131.4	127.9	125.9	4.2	4.3
	3	110.0	113.0	102.2	102.8	8.0	9.9
	4	116.2	117.5	104.0	104.0	11.8	13.0
Bonner - East	5		126.5		122.1		3.6
I-IG 90-2(10) 110	6		124.0		119.1		4.1
	7		119.0		113.0		5.3
	8		126.5		121.1		4.5
	9		114.5		108.7		5.3
	10		102.0		96.8		5.4
	11		118.5		112.9		4.9
	12		118.5		112.9		4.9
	13		125.6		119.2		5.3
	14		121.5		115.0		5.6
	15		129.5		122.2		6.0
	16		122.0		115.6		5.5
	17		120.0		112.9		6.3
	18		121.5		114.6		6.0
	19		122.0		116.1		5.3
	20		117.5		110.9		5.9
	21		120.0		112.9		6.3
	22		112.0		105.2		6.4
	23		117.5		110.4		6.4
	24		118.5		112.3		5.5
	25		115.0		108.9		5.6

Work was being done in District 2 during the first week in October, 1963. An A-1-a(0) soil sample from Project F 209 (4), Gallatin Gateway - North, was taken to the Division Laboratory. The calibration curve for this soil was established in the laboratory as shown below. Refer to the calibration curves on page 18.

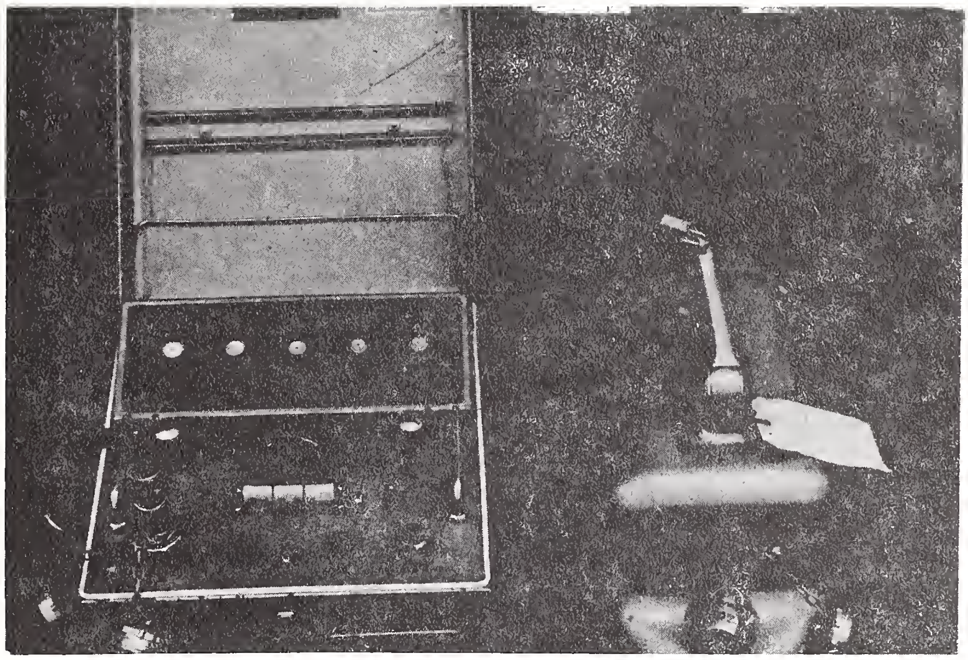
A reinforced box with a volume of 1.954 ft.^{3} was constructed. The box was reinforced with wire straps to retain its shape. A known wet weight of soil was compacted in four-inch lifts. The soil was compacted and then leveled with a straight edge until the entire volume of the box was occupied. Knowing the weight of wet soil added and the volume of the box, we were able to calculate the wet soil density.

$$\text{Density (Wet)} = \frac{\text{Weight of Wet Soil}}{\text{Volume of Box}} = \frac{248.61\ \text{lbs.}}{1.954\ \text{ft.}^3} = 127.9\ \frac{\text{lbs.}}{\text{ft.}^3}$$

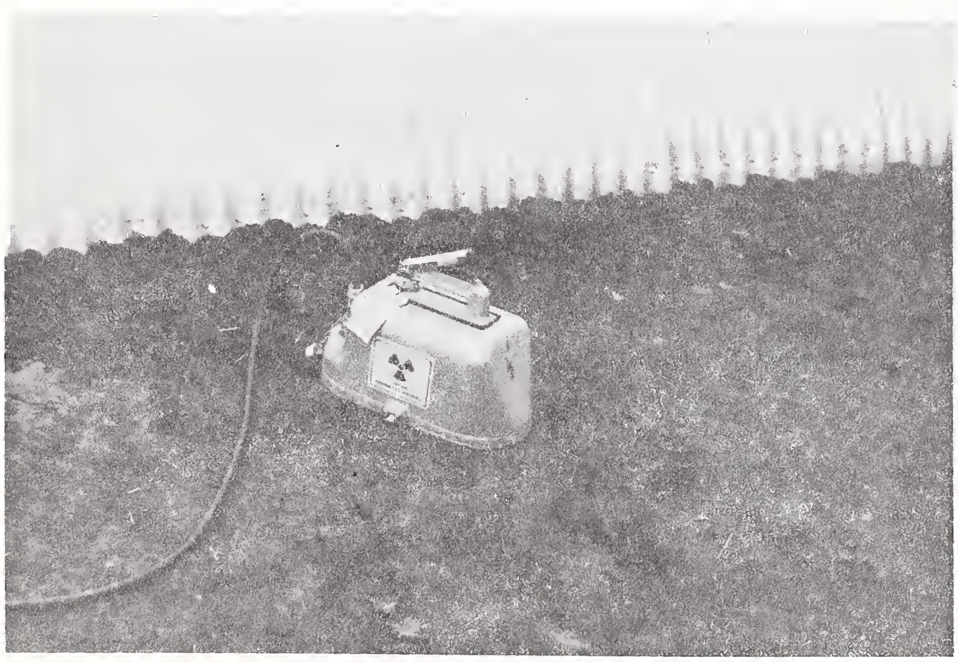
The surface probe was seated on the compacted soil and several counts were recorded. The surface probe was rotated through 360° at 90° intervals. Two one-minute counts were taken at each interval, the average count being 35511 CPM. One point on the curve is established by plotting the average count of 35511 CPM against the wet density of 127.19 lbs./ft.^{3}.

The soil was removed from the box and more water was added. After a thorough mixing, the weighed material was again compacted into the box and leveled as before. The second wet density and average CPM was plotted as before. A line through the two points and paralleling the factory curve represents the curve for this particular soil. About two hours were required to establish the calibration curve.

Moisture-density results were determined at several stations. Tests with the Nuclear device were made first. The test holes for the conventional sand method were in the exact location as the nuclear tests. Comparisons were very erratic. This irregularity in a rocky fill was



Scaler and Surface Probe



Checking compaction near culvert

found to be quite common.

It may be tentatively concluded that the amount of soil measured with the Nuclear device is greater than the amount of soil used for either conventional test. The wide variation in aggregate size allows the Nuclear device to measure the larger, more dense aggregate. This, along with the human errors found in conventional testing, may account for the wide discrepancy in results whenever and wherever they occurred.

Soil samples were taken from Project I-IG 90-6 (10) 282 U1, Logan - Manhattan. The soil classification is A-1-a(0). This soil was taken to the Division Laboratory and, as before, a wet density curve was established.

Referring to the wet density curves, a wide variation can be noted in the curves even though the soil classifications are sometimes the same. For example, Projects I-IG 90-6 (10) 282 U1 and F 209 (4) have the same soils classification, yet the calibration curves are shifted significantly. A CPM of 38500 gives a wet density of 107 lbs/ft^3 for Project I-IG 90-6 (10) 282 U1, and the same 38500 CPM gives a wet density of 114 lbs/ft^3 for Project F 209 (4). Therefore, new curves have to be established regardless of soil classification.

The Logan - Manhattan project was tested with the Nuclear device and with the sand cone. The comparison results for wet density varied between 1 lb/ft^3 and 13 lbs/ft^3. Moisture comparisons with the Speedy Moisture Tester varied from 0.6% to 1.5%. The amount of gravel present made it very difficult to accurately determine densities by the present conventional methods. Refer to Table No. 2 for results.

Project I-IG 90-6 (10) 282 U1, Logan - Manhattan, was tested with the Nuclear device. The soil classification is A-2(4). The material for this particular section contains fine sand and silt. Refer to Table No. 2 for

test results.

Demonstrations were given on Project I 15-1 (17) 46 U1, Pipe Organ - North and South. Highway and construction personnel were generally impressed with the ease of operation and speed of the Nuclear device.

The operator's main concern, at this point, was in trying to determine if control could be maintained on more than one project. Project I-IG 90-4 (7) 205 U1, Opportunity - East and West, is located about 80 miles from the Pipe Organ project. Several moisture-density tests could be determined on both projects during the same day providing the calibration curves were established beforehand. Considering an 8-hour day, 3 hours would be used for traveling and 2½ hours would be used for control of each project. This allows sufficient time to run several complete determinations.

Moisture-density results were determined at two stations with the Nuclear device and the balloon volumeasure. These results were used to establish the calibration curve. This curve crossed the standard factory curve instead of paralleling it. After reviewing the test procedure, a simple error in reading the volumeasure was found. The calculations were corrected and the curve was properly established. The results can be referred to in Table No. 2.

TABLE NO. 2

Location	Test No.	Wet Density ($\frac{lbs}{ft^3}$)		Dry Density ($\frac{lbs}{ft^3}$)		% Moisture	
		Conv.	Nuclear	Conv.	Nuclear	Conv.	Nuclear
Logan -	1	107.9	115.0	100.7	105.6	7.1	8.9
Manhattan	2	117.6	116.0	110.3	107.7	6.7	8.2
I-IG 90-6(10)282 U1	3	120.9	121.0	113.8	113.0	5.7	6.3
	4		115.0		105.6		8.9
	5		116.5		107.7		8.2
	6		125.0		116.4		7.5
	7		124.5		115.9		7.4
	8		126.5		117.2		7.9

Location	Test No.	Wet Density ($\frac{lbs}{ft^3}$)		Dry Density ($\frac{lbs}{ft^3}$)		% Moisture	
		Conv.	Nuclear	Conv.	Nuclear	Conv.	Nuclear
	9		119.0		110.5		7.7
	10		142.0		133.5		6.4
	11		124.5		112.3		9.9
	12		132.0		113.6		13.5
	13		134.0		120.9		10.8
Gallatin Gateway - North F 209 (4)	14		115.5		108.5		6.4
	15		94.7		84.8		11.7
	16		127.0		121.9		4.2
	17		131.5		122.1		7.7
	18		116.5		103.1		13.0
	19		129.5		123.4		4.9
	20		112.5		99.3		13.3
	21		123.8		117.0		4.0
	22		119.5		111.4		7.1
McLeod - Big Timber S 28 (7)	23		105.0		98.2		6.9
	24		109.0		96.0		13.0
Opportunity - East and West I-IG 90-4(7)205 U1	25	117.5	125.5	105.5	116.8	8.9	7.4
	26	120.5	110.5	110.6	101.0	8.9	9.4
	27	105.0	118.0	97.3	108.7	8.8	8.5
	28	127.8	125.5	117.7	120.2	6.3	6.6
	29	136.0	128.5	129.5	121.1	5.1	6.1
	30	136.0	136.0	136.0	128.8	4.2	5.6
	31		125.5		116.8		7.4
	32		131.0		120.8		8.4
	33		110.5		101.0		9.4
	34		118.0		108.7		8.5
	35		125.5		117.7		6.6
	36		128.5		121.1		6.1
	37		136.0		128.8		5.6
Pipe Organ - North and South I 15-1(17)46 U1	38		105.0		98.2		6.9
	39		109.0		96.0		13.0

Two projects were tested in District 3--Project F 149 (19), Great Falls - Fort Benton, and Project I 15-4 (18) 210, Wolf Creek Canyon. The soil classifications are A-4(4) and A-1-a(0) respectively.

The curve for the Great Falls - Fort Benton projects were established in the field with conventional equipment. The curve for the Wolf Creek Canyon job was established in the Division Laboratory. Refer to Table No. 3, tests number 1 through 21.

TABLE NO. 3

Location	Test No.	Wet Density ($\frac{lbs}{ft^3}$)		Dry Density ($\frac{lbs}{ft^3}$)		% Moisture	
		Conv.	Nuclear	Conv.	Nuclear	Conv.	Nuclear
Great Falls - Fort Benton	1	123.0	125.0	107.2	109.2	14.9	14.5
F 149 (19)	2	122.5	128.0	107.4	112.8	14.2	13.5
	3	115.0	125.5	99.1	109.5	16.3	14.6
	4	130.4	122.0		109.7		10.3
	5	119.9	123.0		114.6		7.3
	6		125.0		109.2		14.3
	7		128.0		112.8		13.5
	8		125.5		109.5		14.6
	9		122.0		109.7		10.3
	10		123.0		114.6		7.3
Wolf Creek Canyon	11		97.5		9.7		6.2
I 15-4 (18) 210	12		118.0		112.8		4.6
	13		114.5		108.5		5.6
	14		111.0		104.8		5.9
	15		128.5		120.5		6.7
	16		124.0		116.0		6.9
	17		125.0		118.5		5.6
	18		128.5		120.5		6.7
	19		132.0		124.5		5.8
	20		127.0		119.7		6.1
	21		129.0		113.2		13.1
Simpson - Canadian Line	22	136.0	137.5	127.8	127.6	7.0	7.8
S 30 (13)	23	130.0	131.0	121.7	122.2	7.1	7.2
	24		124.1		113.7		9.2
	25		137.5		127.6		7.8
	26		131.0		122.2		7.2
	27		129.0		118.9		5.3

This research project was continued for two months in the Fall of 1963. Projects in three Districts were tested with the Nuclear device. Comparison tests with the present conventional methods were determined whenever possible. Several demonstrations were given to highway and construction personnel. During this time, some valuable information has been gained concerning the distribution, control, and efficiency of the Nuclear device. This will be referred to later in the report.

Field investigations were continued in April, 1964. Interstate Projects I 90-8 (1) 444, Billings West Interchange, and I 90-8 (17) 433 U1, Laurel - Mossmain, were the first to be tested.

Moisture-density tests on the Billings West project were determined on the ramps leading to the bridge structures. Most of the soil was an A-6(11) class. The comparison results with the sand cone and the balloon volumeasure were good. A majority of the wet density comparisons were within 3 lbs/ft^3 and the moisture contents were within 2%. The wet density curve was established in the field with conventional equipment. The test results are listed in Table No. 4.

A soil sample of 3 inch base material from the Laurel - Mossmain project was compacted into the standard volume box. After establishing the wet density curve for this soil, compaction tests were determined at several stations. The results are tabulated in Table No. 4.

TABLE NO. 4

Location	Test No.	Wet Density ($\frac{lbs}{ft^3}$)		Dry Density ($\frac{lbs}{ft^3}$)		% Moisture	
		Conv.	Nuclear	Conv.	Nuclear	Conv.	Nuclear
Billings West	1	131.5	128.0	113.0	113.2	16.3	13.1
Interchange	2	121.8	121.5	107.8	107.7	13.0	12.8
I 90-8(11) 444	3	127.0	128.7	108.9	112.6	16.9	14.3
	4	117.0	107.0	100.5	92.6	16.9	15.2
	5	113.9	112.5	96.0	95.0	18.3	18.4
	6		128.0		113.2		13.1
	7		121.5		107.7		12.8
	8		128.7		112.6		14.3
	9		107.0		92.9		15.2
	10		112.5		95.0		18.4
	11		125.0		116.5		7.3
	12		135.0		128.2		5.3
Laurel - Moss-main	13		131.0		120.8		8.4
	14		136.0		131.5		4.2
I 90-8(17)433 U1	15		135.0		130.0		3.9
	16		138.5		134.0		3.4
	17		133.0		128.0		4.0
Kings Ave. West	18		121.0		108.1		11.9
S 192 (7)	19		111.2		99.4		12.9

The last week in April, 1964, was spent in District 4. Project I 94-6 (8) 221 U1, Wibaux County Line - West, was tested with the Nuclear device. The soil classifications are A-7-6(11) and A-6(13).

The A-7-6(11) soil has a maximum dry density of 98.6 lbs/ft^3 and optimum moisture of 23.5%. The maximum dry density for the A-6(13) soil is 106.8 lbs/ft^3 and optimum moisture of 19.5%. Several conventional determinations were made with the balloon volumeasure to establish the wet density curve. A good curve was not established using the results of conventional testing. At this point, it was not known whether the conventional or the Nuclear device was causing the discrepancy.

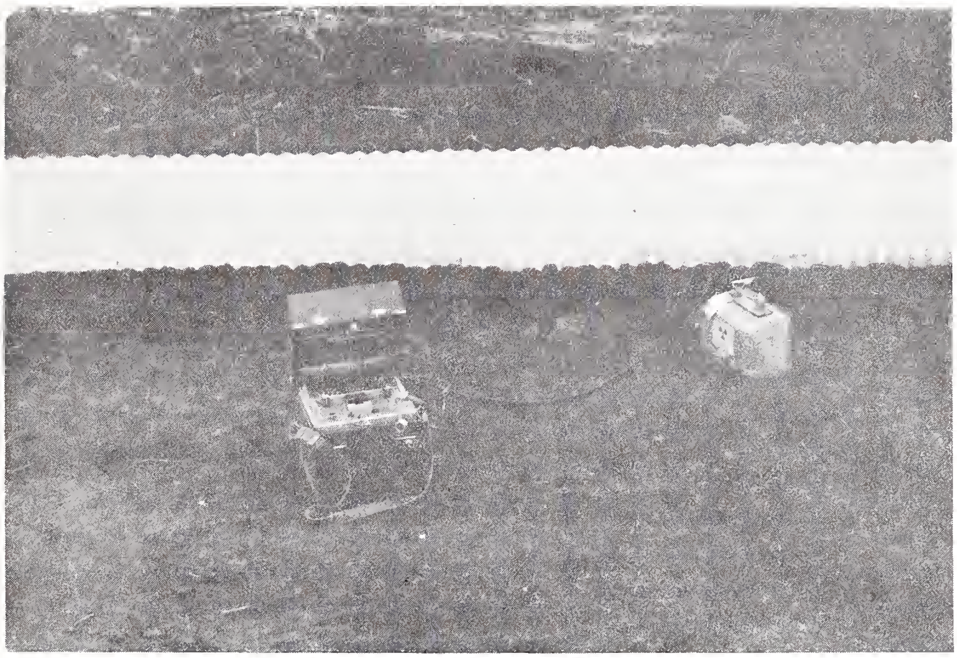
Samples of the clay soil were taken into the Division Laboratory and a calibration curve was established. This curve seemed to be more realistic for this type of soil.

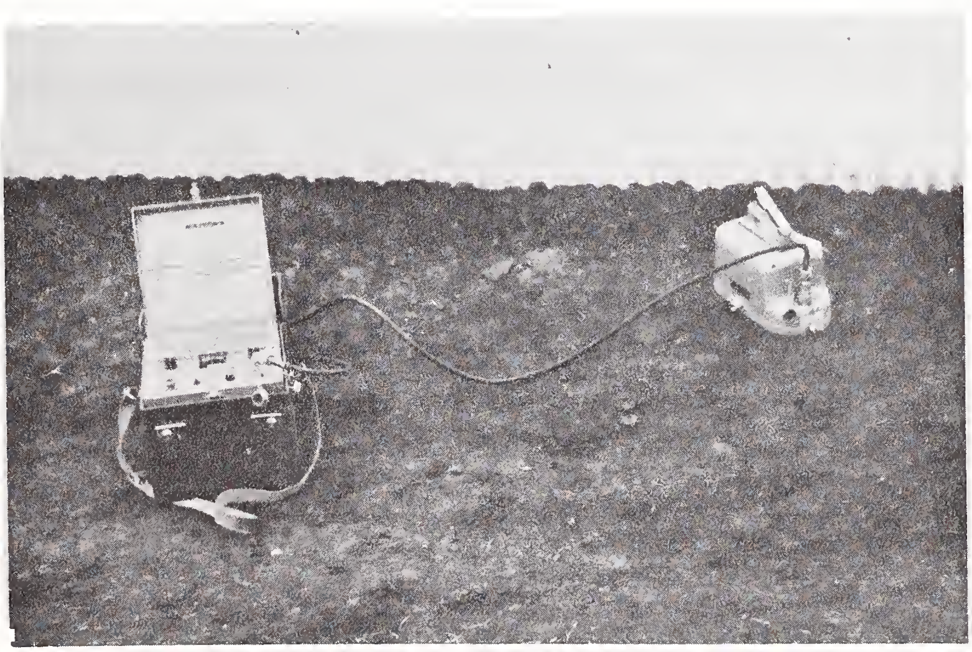
Field comparisons with the balloon volumeasure showed a wide variety of results. The conventional test results were much higher than the test results with the Nuclear device.

With the Nuclear device, some irregularity in the moisture content was suspected because of the small amount of organic material present. The trouble was later attributed to the conventional tests. Human error with regard to operating procedure accounted for the majority of error. Some of the tests with the Nuclear device can be referred to in Table No. 5.

TABLE NO. 5

Location	Test No.	Wet Density ($\frac{lbs}{ft^3}$)		Dry Density ($\frac{lbs}{ft^3}$)		% Moisture	
		Conv.	Nuclear	Conv.	Nuclear	Conv.	Nuclear
Wibaux County	1		98.0		81.8		19.8
Line	2		98.0		85.4		14.7
I 94-6(8)221 U1	3		98.0		83.0		18.1
	4		97.0		80.8		20.0
	5		99.5		81.3		22.2
	6		100.5		83.3		20.8
	7		99.8		86.4		15.5





Scaler and Surface Probe, checking compaction near culvert

To be certain that the Nuclear device was functioning properly, more testing was conducted with the clay soils from the Wibaux County Line project. This testing was done in the Central Laboratory.

An A-7-6(11) soil was tested first. The soils were thoroughly mixed before each test. Enough wet soil was weighed to fill the first 7 inches in the bottom of the box. The material was compacted with a Marshall hammer to about 4 inches. The above procedure was followed until the entire volume of the box was filled with compacted soil. The weight of wet soil added in (pounds) and the volume of the box in (cubic feet) is used to calculate a standard wet density of 98.09 lbs/ft^3.

The Nuclear device was seated on the compacted soil and two CPM were taken for density and moisture. The probe was turned 90° and two more CPM were taken in the density and moisture positions. The above procedure was followed at 90° intervals until four complete determinations were made. Several locations were tested to determine a good average count. The reproducibility of the CPM at different locations in the box were well within the allowable tolerance; thus indicating that the density throughout the box was quite uniform.

Conventional methods were used to determine the in-place density as compared with the standard wet density of 98.09 lbs/ft^3. Test holes were augered in the compacted soil. The volume of these holes were each determined with the balloon, sand, and by actual lineal measurement. The oven-dry moisture contents were compared with the moisture determined by the Nuclear device. Refer to the following table for comparison results.

TABLE No. 6

METHOD	HOLE NO.	WET DENSITY lbs/ft^3	MOISTURE %	
			Oven Dry	Nuclear
Standard	1	98.09	9.65	9.36
Sand	1	102.50		
Balloon	1	101.69		
Lineal Measurement	1	99.95		

METHOD	HOLE NO.	WET DENSITY lbs/ft^3	MOISTURE %	
			Oven Dry	Nuclear
Standard	2	98.09	8.96	9.36
Sand	2	98.40		
Balloon	2	97.89		
Lineal Measurement	2	100.70		

The wet density determined by the sand method is higher for test hole number 1. A variation in density of 4 lbs/ft^3 by the sand method is not uncommon, both in the laboratory and field. The slightest change in the method of pouring the sand in the test hole appears to be one of the sources of error. Another error may result from the changing density of the sand itself. Repeat determinations of sand density seem to verify this.

Another soil from the same project in District 4 was tested in the Central Laboratory. The soil is an A-6(13) type with a maximum density of 106.8 lbs/ft^3 and optimum moisture of 19.5%. The test results for this soil were very similar to those found in Table No. 6.

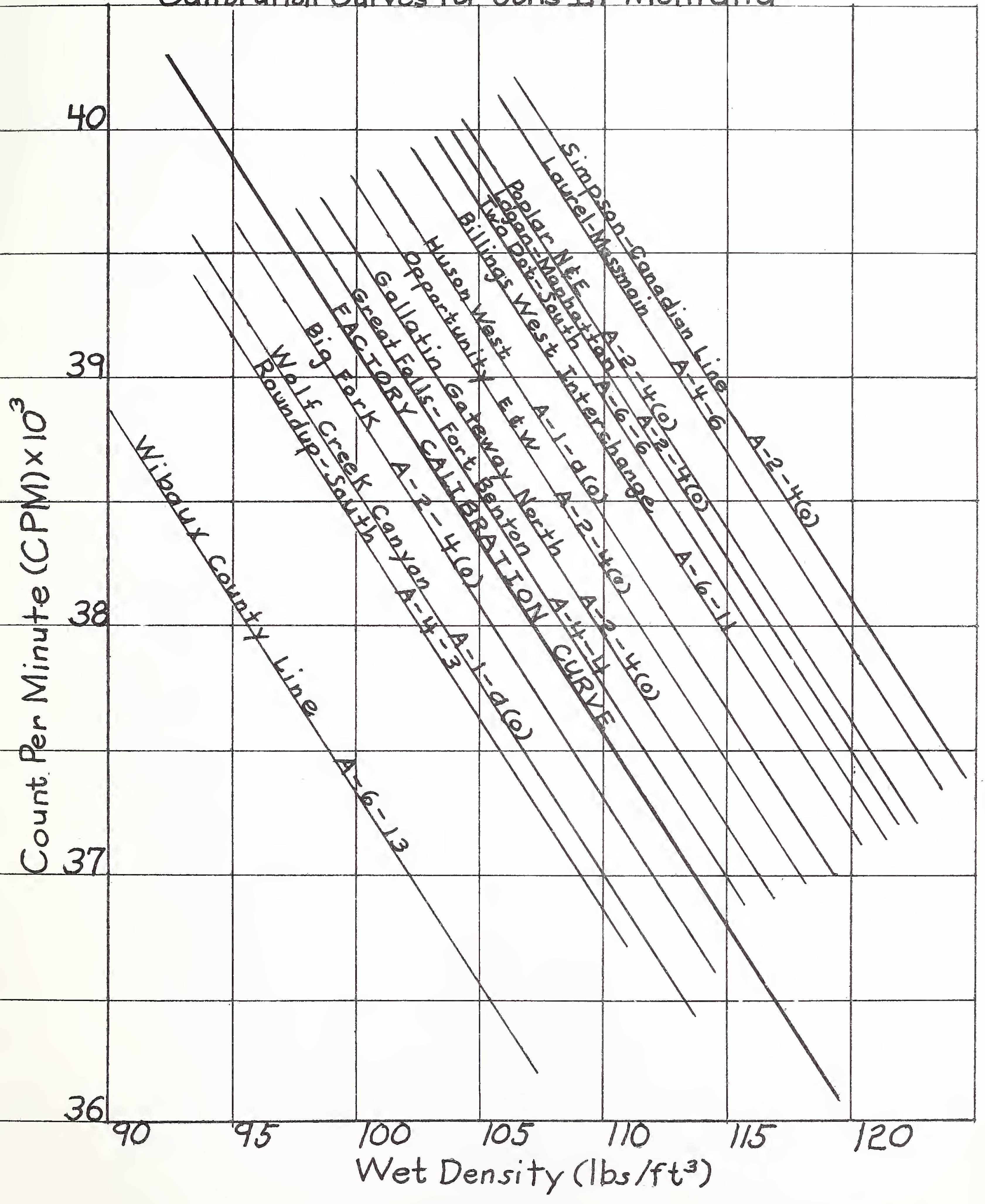
The points established for the calibration curve are close to those of the curve that was previously established in the District 4 Laboratory. The consistency in wet density throughout the box was confirmed by the repeatability of the CPM with the Nuclear device. Therefore, it was assumed that the Nuclear device was functioning properly.

Construction projects were tested in all the Districts. Comparative test results were determined whenever possible. The results for the remainder of the projects can be referred to in Table No. 7

TABLE NO. 7

Location	Test No.	Wet Density ($\frac{lbs}{ft^3}$)		Dry Density ($\frac{lbs}{ft^3}$)		% Moisture	
		Conv.	Nuclear	Conv.	Nuclear	Conv.	Nuclear
Billings -	1	103.8	101.0	94.2	92.6	10.2	9.1
Roundup	2	105.1	104.5	96.6	97.1	8.7	7.6
F 108 (9)	3	110.5	110.0	100.6	101.0	9.8	8.9

Calibration Curves For Soils In Montana



Location	Test No.	Wet Density ($\frac{lbs}{ft^3}$)		Dry Density ($\frac{lbs}{ft^3}$)		% Moisture	
		Conv.	Nuclear	Conv.	Nuclear	Conv.	Nuclear
Two Dot - South	4	122.9	123.0	110.1	110.8	11.6	11.0
S 18 (6)	5	107.1	123.0	97.0	111.9	10.4	9.8
	6		111.3		102.3		8.8
	7		123.0		111.9		9.8
	8		123.0		110.8		11.0
Poplar North and	9	108.0	105.0	100.0	92.0	8.0	14.2
East	10	125.3	111.0	114.5	97.2	9.9	14.2
S 418 (3)	11		111.0		97.2		14.2
	12		105.0		92.0		14.2
Simpson -	13	136.0	137.5	127.8	127.6	7.0	7.8
Canadian Line	14	130.0	131.0	122.2	122.2	7.1	7.2
S 301 (13)	15		124.1		113.7		9.2
	16		137.5		127.6		7.8
	17		131.0		122.2		7.2
	18		129.0		118.9		5.3
Bigfork	19	120.5	118.0	106.2	106.4	13.6	10.9
S 65 (7)	20	123.0	119.0	107.2	107.2	14.6	11.0
	21	118.0	119.5	104.0	102.9	15.0	16.1
	22	116.0	117.5	103.0	105.1	11.0	11.8
	23		118.0		106.4		10.9
	24		119.0		107.2		11.0
	25		119.5		102.9		16.1
	26		117.5		105.1		11.8

RADIATION EXPOSURE

The Montana Highway Testing Laboratory is on a monthly film badge service with the Nuclear Chicago Corporation. Each badge contains two films, one for Neutron radiation and one for Gamma radiation. A control badge, along with four other badges, was used. The control badge was stored in a drawer free from the radiation emitted from the Nuclear device. One badge was placed at waist level on the front of a belt. This badge was worn about ten hours a day. Another badge was worn on the front of the pants cuff while operating the equipment. Two more badges were used as extras, and were kept in a small box in the rear seat of the vehicle. The probe was carried in the trunk of the vehicle. The exposure during the first month's use is as follows:

Film Badge No.	Gamma Radiation	
000	0 MRems	Control
001	59 MRems	Worn on waist
002	88 MRems	Worn on pants cuff
003	85 MRems)	Set in a box on the
004	92 MRems)	rear seat of the vehicle

Film Badge No.	Neutron Radiation	
8000	0 MRems	Control
8001	10 MRems	Worn on waist
8002	35 MRems	Worn on pants cuff
8003	30 MRems)	Set in a box on the
8004	5 MRems)	rear seat of the vehicle

On overnight trips during the month, badges 3 and 4 would remain on the rear seat of the vehicle. Therefore, the radiation recorded by these films represents several 24-hour periods of exposure. Film badge number 1 is of major concern because it indicates exposure of the entire body to radiation. Exposure over a period of years may be too high for the Highway Department to consider using this equipment for control work.

Notification by the manufacturer, Tellurometer, Inc., of modifications to be performed with their present production model presented an opportunity to send the equipment back for a complete check. Tellurometer, Inc., had the Nuclear device for approximately two months. During this time, modifications were made to increase the reliability, operation, repeatability and accuracy of the Nuclear device. The equipment will now operate at all temperatures ranging from $-5^{\circ}F$ to $120^{\circ}F$. In addition, the Nuclear device will now withstand more rugged treatment in the field consistent with highway construction.

The manufacturer had sent the equipment to Tracer Laboratory, Inc., for a complete check on the amount of radiation received during normal operation. The Nuclear device was tested under all conditions, simulating those encountered in the field with respect to handling the equipment, seating it, and transporting it. A complete series of smear tests were

made to check for radiation leakage. This testing program did not reveal that personnel exposure should exceed accepted maximum permissable levels for occupational workers.

The equipment was received by the Montana Highway Testing Laboratory during the early part of February, 1964. Because of adverse weather conditions hindering construction in February and March, we were unable to use the Nuclear device in the field until April. The same testing procedure was followed as in previous field testing. Awareness as to time in contact with the probe was always demonstrated. The film badge reports were more favorable. A typical example of the radiation exposure can be referred to below:

Film Badge No.	Gamma Radiation	
000	0 MRems	Control
001	0 MRems	Worn on waist
002	0 MRems	Worn on pants cuff
003	0 MRems)	Kept with control badges
004	0 MRems)	

Film Badge No.	Neutron Radiation	
8000	0 MRems	Control
8001	0 MRems	Worn on waist
8002	10 MRems	Worn on pants cuff
8003	10 MRems)	Kept with control badges
8004	10 MRems)	

The first film exposure report was the only one that was above the expected. All subsequent exposure reports were similar to the one shown above. This report does not indicate excessive exposure and thus satisfies the personnel working with the equipment.

At this time, an attempt is being made to evaluate the test procedure employed during the first month's testing to arrive at a possible explanation for the higher level of exposure. A list of possibilities is as follows:

(1) Familiarization with the equipment required, more time being spent in operating the Nuclear device.

(2) The possibility of lingering when seating the probe and not realizing the time consumed.

(3) A few more tests were determined during the first month which would contribute to an increase in exposure.

(4) The modifications that were made by the manufacturer may have had some effect on the radiation released.

We have received about ten exposure reports that represent radiation received during field and laboratory testing. All of the monthly reports, except the first, were below 15 MRems total for Gamma and Neutron radiation. It is felt, from reading other reports and from the manufacturer's representation, that this level of radiation is about average for equipment of this type. By taking the proper precautions during testing, an operator should be able to keep the radiation received within this range.

COST COMPARISON, EFFICIENCY AND DISTRIBUTION

Cost Comparison

The present cost of furnishing conventional equipment for one field tester is approximately $400.00. The State of Montana has spent approximately $17,000.00 equipping the entire state with this latest conventional equipment. The Nuclear device used by the Highway Department cost about $4,000.00. Similar equipment by different manufacturers can be purchased up to a cost of approximately $5,000.00. The advantages one Nuclear device has over the other would have to be investigated.

There would be a certain amount of maintenance cost involved with the Nuclear device. It could be expected that electrical components would have to be replaced after a length of time. These replacements could be made by select individuals working within the Highway Department.

Efficiency

The present conventional field equipment enables a tester to run about eight complete moisture-density determinations in one day. The method employing the Rubber Balloon Volumeasure and the Speedy Moisture Tester has greatly increased the ability to control construction projects. The disadvantages in the use of the above method for compaction control is due to the inaccuracy in testing a rocky fill. Because of the larger irregular aggregate, a good uniform hole is difficult to obtain. Once the test hole is dug, it is very difficult to get the true volume of the test hole. The balloon does not completely fill the area around the aggregate. There were only a few instances in which duplicate testing with the "Speedy" showed varying results. The comparisons with oven dried samples were generally very good.

The Nuclear device, which the Montana Highway Department has, enables the operator to complete a moisture-density in about eight minutes. Approximately 35 completed tests can be made in one day. The greater number of determinations insures more control, along with less delay, for the contractor. There is no time lost for digging test holes. The Nuclear device has the advantage of determining accurate tests in moderately rocky fills.

Distribution

During the field investigation with the Nuclear device, every Division in the State of Montana was entered. Several factors affecting the distribution of the Nuclear equipment were studied. Some of these factors can be referred to as follows:

(1) The area of the state of Montana is large.

(2) In some Divisions, the distances between projects is great. There were some instances when it was impossible to control compaction on separate projects in the same day because of the distance involved between them.

(3) The majority of the work is concentrated in Divisions containing Interstate projects.

Upon completion of the field work, a questionaire was sent to some of the field personnel in each Division who had worked with the operator during the field phase of this project. They were asked if they felt that the Nuclear device should replace present conventional equipment. Some were of the opinion that the present equipment is perfectly satisfactory, and others felt that the Nuclear device should replace the present equipment as soon as possible. When questioned as to the number of Nuclear devices they felt would properly cover their Division, the answers varied from one in some Divisions to five in others.

It is the opinion of the writer that one Nuclear device in each Division, along with some assistance from the present conventional equipment, would properly control the compaction. The embankment work in some of the Divisions could be controlled entirely by using one Nuclear device. Other Divisions may have to rely primarily on assistance from the present conventional equipment.

Each Nuclear device could be controlled on the Division level. Periodic maintenance checks, calibration checks, and leakage investigations should be made by individuals from the Central Laboratory. A supply of parts, along with an extra Nuclear device, should be maintained in the Central Laboratory.

CONCLUSIONS

(1) The soil calibration curves can be established in a short time.

(2) In fine soils, calibration curves can be determined by the Nuclear device with some help from the present conventional equipment.

(3) Embankment soils containing much coarse aggregate should be calibrated with the standard volume container referred to earlier in the report.

(4) Soil calibration curves have to be established for soils of different chemical composition. The slightest variation in soil can produce a shift in the wet density curve. Refer to the wet density calibration curves on page number 18.

(5) A fine dry sand should be used to seat the probe. If at all possible, this fine sand should be screened from the fill material.

(6) Accurate moisture-densities can be determined with the Nuclear device provided the material is -3 inch size. Moisture-density tests on the larger material are not as reliable.

(7) Comparison tests were favorable on embankments containing fine soil. Conventional tests in rocky fills appear to be unreliable, causing considerable variations in comparison with the Nuclear device.

(8) The Nuclear equipment is faster than the present conventional testing equipment. Once the calibration curves are established for each soil, it takes approximately ten minutes to complete a moisture-density determination.

(9) Control on more than one project can be maintained with proper distribution and assignment of the Nuclear devices to the projects.

(10) Reliable tests can be determined with the Nuclear device providing care is exercised in seating the probe along with close adherence to the operating procedure.

(11) The Nuclear device is rugged enough to withstand the rough treatment experienced with Highway construction.

(12) The total radiation received can be kept at a low level with proper handling and by following the recommended and established operating procedure along with proper supervision.

(13) Highway and construction personnel were impressed with the simplicity of operation of the Nuclear equipment along with the speed in testing.

(14) Personnel can be trained to operate the equipment in a few days. These people should have a good knowledge of soils identification.

RECOMMENDATIONS

(1) The different companies who manufacture similar types of Nuclear equipment, should be given a chance to demonstrate and prove their Nuclear device. In this way, the Highway Department would be insured of receiving the equipment that would best fit our needs.

(2) Responsible field personnel, who are permanent employees with the Highway Department, would be trained to operate the Nuclear device. These personnel should have a good knowledge of soils and should be familiar with elementary electricity. No particular skill or education is required to properly operate the Nuclear device.

(3) The Division Laboratories should be responsible for the

distribution and handling of the equipment in each Division. The Central Laboratory in Helena would have the responsibility of training personnel along with general supervision and maintenance.

(4) A supply of parts kept in the Central Laboratory would facilitate problems.

(5) One vehicle should be assigned for each Nuclear device. The equipment should be set on a rack and strapped down in the rear of a vehicle.

(6) Method "D" of AASHO Designation: T99-57 should be used for establishing the maximum dry density. This method has a correction for the -2 inch, +3/4 inch material.

OPERATING PROCEDURE FOR HIDRODENSIMETER

(1) Connect the Probe to the Scaler by means of the connecting cable.

(2) Place the Surface Calibration Unit on a wooden box about 14 inches above the ground.

(3) Place the Probe on the Calibration Unit so that the red dot on the front of the cover is over either the letter "A" or "B", and then fasten the retaining clips. The top face of the Calibration Unit and the sole plate of the Probe must be clean.

(4) The equipment should be positioned at least two feet from any solid object in order to minimize reflections.

(5) With the source in operating position, check the counts obtained to see that they are within the specified allowable tolerances for the position used. Steps number 1 through 5 should be followed at the beginning of each day's testing.

(6) The source should be in the shielded or safe position.

(7) A test area about 18 inches square is prepared with a shovel or scraper. A fine dry sand can be used for bedding the Probe.

(8) The Probe is moved back and forth on the fine dry sand until only a thin layer of sand remains between the bottom of the Probe and the surface of the ground.

(9) With the source in operating position, a CPM in the density position is determined. After two counts for density and two counts for moisture, the Probe is reversed 180° and step 9 is repeated.

(10) The average CPM for density is calculated and the wet density is found by referring to the previously established wet density calibration curve.

(11) The average CPM for moisture is calculated, and by referring to the factory curve, the lbs/ft^3 of moisture is determined.

(12) The dry density is determined by subtracting the moisture content in lbs/ft^3 from the wet density in lbs/ft^3.

(13) The ratio of moisture content to dry density multiplied by 100 gives percentage moisture content based on dry weight.

(14) The ratio of dry density (actual field density) to the maximum dry density (Proctor), multiplied by 100, gives the percent compaction.

ACKNOWLEDGEMENT

Various report by other investigators were reviewed. These reports were made available by courtesy of the Colorado Highway Department, Oklahoma Highway Department and the Michigan Highway Department.

Appreciation is extended to the Montana Highway Department's field personnel for their cooperation in making the project a success.

Appreciation is also extended to Mr. Roy H. Gagle, Materials Engineer, and Mr. Stephen F. Weber, Assistant Materials Engineer, for their assistance and advice. Also, sincere thanks to personnel in the Central Laboratory who helped with the project.